Muon Anomalous Magnetic Moment and Leptoquark Solutions

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The recent measurement on the muon anomalous magnetic moment a_μ shows a 2.6σ deviation from the standard model value. We show that it puts an interesting bound on the mass of the second generation leptoquarks. To account for the data the leptoquark must have both the left- and right-handed couplings to the muon. Assuming that the couplings have electromagnetic strength, the mass is restricted in the range 0.7 TeV $< M_{\rm LQ} <$ 2.2 TeV at 95% C.L. We also discuss constraints coming from other low energy and high energy experiments. If the first-second-generation universality is assumed, constraints come from the atomic parity violation and charged-current universality. We show that coexistence with other leptoquarks can satisfy these additional constraints and at the same time do not affect the a_μ.

Many Grand-Unified theories predict the existence of leptoquarks, which are composite objects that carry both the lepton and quark numbers. The discovery of such particles certainly affects the planning for future experiments and guides the building of the theories. In fact, leptoquarks have been actively searched for in many collider experiments [1,2], and will still be in the future. Precision measurements are also very useful in testing leptoquark models and restricting the parameter space. The measurement of the anomalous magnetic moment of leptons [3,4] is one of such experiments that can constrain the model.

The recent measurement on the muon anomalous magnetic moment by the experiment E821 [5] at Brookhaven National Laboratory has reduced the error to a substantially smaller level. Combining with previous measurements the new world average is [6]

$$a_\mu^{\rm exp} = 116\,592\,023\,(151)\ \times\ 10^{-11}\ , \tag{1}$$

where the standard model (SM) prediction is

$$a_\mu^{\rm SM} = 116\,591\,597\,(67)\ \times\ 10^{-11}\ , \tag{2}$$

in which the QED, hadronic, and electroweak contributions have been included. Thus, the deviation from the SM value is

$$\Delta a_\mu \equiv a_\mu^{\rm exp} - a_\mu^{\rm SM} = (42.6\ \pm 16.5)\ \times\ 10^{-10}\ . \tag{3}$$

This 2.6σ deviation may be a hint to new physics because the deviation is beyond the uncertainties in QED, electroweak, and hadronic contributions.

Among various extensions of the SM, namely, supersymmetry [7], additional gauge bosons [8], leptoquarks [3,9,10], extra dimensions, muon substructure [11], they all contribute to a_μ. However, not all of them can contribute in the right direction as indicated by the data. Thus, the $a_\mu^{\rm exp}$ measurement can differentiate among various models, and perhaps with other existing data can put very strong constraints on the model under consideration.

In this Letter, we investigate the contributions of various leptoquarks to a_μ. We limit to the second generation leptoquarks only without considering any generation mixing in order to avoid dangerous flavor changing neutral currents. Our main result is summarized as follows. To account for the a_μ data the solution requires a leptoquark that has both the left-handed and right-handed chiral couplings and the mass is required to be about $0.7 - 2.2$ TeV for an electromagnetic coupling strength. This solution is consistent with direct and indirect experimental search. The a_μ data disfavors, if not rule out, the leptoquarks that have only a left- or right-handed coupling. Also, coexistence with other leptoquarks can easily satisfy additional constraints, e.g., atomic-parity violation (APV) and charged-current (CC) universality, without affecting the a_μ.

While we are completing this work, a paper [9] appears, which describes similar solutions to a_μ including the $\mu - t$ leptoquarks. Although this $\mu - t$ leptoquark could imply a very large contribution to a_μ because of the large top quark mass, it could, however, give rise to flavor-changing processes such as $t \to c\gamma, c\mu^+\mu^-$. We do not consider this option. Besides, we also have some sign differences in the main result.

The interaction Lagrangians for the $F = 0$ and $F = -2$ (F is the fermion number) scalar leptoquarks are [12]

$$\mathcal{L}_{F=0} = \lambda_L \overline{\ell_L} u_R \mathcal{S}^L_{1/2} + \lambda^*_R \overline{q_L} e_R (i\tau_2 \mathcal{S}^{R*}_{1/2}) + \tilde\lambda_L \overline{\ell_L} d_R \tilde{\mathcal{S}}^L_{1/2} + h.c.\ , \tag{4}$$

$$\mathcal{L}_{F=-2} = g_L \overline{q^{(c)}_L} i\tau_2 \ell_L \mathcal{S}^L_0 + g_R \overline{u^{(c)}_R} e_R \mathcal{S}^R_0 + \tilde g_R \overline{d^{(c)}_R} e_R \tilde{\mathcal{S}}^R_0 + g_{3L} \overline{q^{(c)}_L} i\tau_2 \vec\tau \ell_L \cdot \vec{\mathcal{S}}^L_1 + h.c. \tag{5}$$

where q_L, ℓ_L denote the left-handed quark and lepton doublets, u_R, d_R, e_R denote the right-handed up-type quark, down-type quark, and lepton singlet, and $q_L^{(c)}, u_R^{(c)}, d_R^{(c)}$ denote the charge-conjugated fields. The subscript on leptoquark fields denotes the weak-isospin of the leptoquark, while the superscript (L,R) denotes the handedness of the lepton that the leptoquark couples to. The color indices of the quarks and leptoquarks are suppressed. The components of the $F=0$ leptoquark fields are

$$\mathcal{S}^{L,R}_{1/2} = \begin{pmatrix} S^{L,R(-2/3)}_{1/2} \\ S^{L,R(-5/3)}_{1/2} \end{pmatrix} \ , \qquad \tilde{\mathcal{S}}^{L}_{1/2} = \begin{pmatrix} \tilde{S}^{L(1/3)}_{1/2} \\ -\tilde{S}^{L(-2/3)}_{1/2} \end{pmatrix} \ , \tag{6}$$

where the electric charge of the component fields is given in the parentheses, and the corresponding hypercharges are $Y(\mathcal{S}^L_{1/2}) = Y(\mathcal{S}^R_{1/2}) = -7/3$ and $Y(\tilde{\mathcal{S}}^L_{1/2}) = -1/3$. The $F=-2$ leptoquarks $\mathcal{S}^L_0, \mathcal{S}^R_0, \tilde{\mathcal{S}}^R_0$ are isospin singlets with hypercharges $2/3, 2/3, 8/3$, respectively, while $\mathcal{S}^L_1$ is a triplet with hypercharge $2/3$:

$$\mathcal{S}^L_1 = \begin{pmatrix} S^{L(4/3)}_1 \\ S^{L(1/3)}_1 \\ S^{L(-2/3)}_1 \end{pmatrix} \ . \tag{7}$$

The $\mathrm{SU}(2)_L\times \mathrm{U}(1)_Y$ symmetry is assumed in the Lagrangians of Eqs. (4) and (5).

To calculate the contribution to a_μ we start with the $F=0$ leptoquark $\mathcal{S}^{L,R}_{1/2}$ that has both the left- and right-handed couplings. The other leptoquarks with either left- or right-handed couplings are simply special cases of it. The Lagrangian can be rewritten as

$$\mathcal{L}_{\mathcal{S}_{1/2}} = \bar{\mu}(\lambda_L P_R + \lambda_R P_L) c\, \mathcal{S}^{(-5/3)}_{1/2} \quad + h.c.\ , \tag{8}$$

where $P_{L,R} = (1\mp\gamma^5)/2$ and we explicitly write the second generation particles μ and c-quark. The result can be easily obtained by some modifications on a $\mu\to e\gamma$ [13] calculation, as follows (a_μ is defined by $\mathcal{L} = (e/4m_\mu) a_\mu \bar{\mu}\sigma_{\alpha\beta}\mu F^{\alpha\beta}$)

$$\Delta a_\mu(\mathcal{S}_{1/2}) = -\frac{N_c}{16\pi^2}\frac{m_\mu^2}{M^2_{\mathcal{S}_{1/2}}}\left\{ (|\lambda_L|^2+|\lambda_R|^2)(Q_c F_5(x) - Q_S F_2(x)) + \frac{m_c}{m_\mu}\mathcal{R}e(\lambda_L\lambda_R^*)(Q_c F_6(x) - Q_S F_3(x))\right\} \ , \tag{9}$$

where

$$\begin{aligned}
F_2(x) &= \frac{1}{6\,(1-x)^4}\,(1-6\,x+3\,x^2+2\,x^3-6\,x^2\,\ln x)\ ,\\
F_3(x) &= \frac{1}{(1-x)^3}\,(1-x^2+2\,x\,\ln x)\ ,\\
F_5(x) &= \frac{1}{6\,(1-x)^4}\,(2+3\,x-6\,x^2+x^3+6\,x\,\ln x)\ ,\\
F_6(x) &= \frac{1}{(1-x)^3}\,(-3+4\,x-x^2-2\,\ln x)\ .
\end{aligned}$$

In the above expression, $N_c = 3, Q_c = 2/3, Q_S = -5/3$, and $x = m_c^2/M^2_{\mathcal{S}_{1/2}}$, and we have neglected terms proportional to $m_\mu^2/M^2_{\mathcal{S}_{1/2}}$ in the parenthesis. Our expression agrees with that in Ref. [4].

For the $F=-2$ leptoquarks only $\mathcal{S}^{L,R}_0$ has both the left- and right-handed couplings. The Lagrangian can be rewritten as

$$\mathcal{L}_{S_0} = \bar{\mu}(g_L^* P_R + g_R^* P_L)\, c^{(c)}\, \mathcal{S}^{*(-1/3)}_0 \quad + h.c.\ . \tag{10}$$

The contribution to a_μ can be obtained from Eq. (9) with the following substitutions

$$m_c \to -m_c\ , \qquad Q_c \to Q_{c^{(c)}}\ , \qquad \lambda_{L,R}\to g^*_{L,R}\ , \tag{11}$$

where $Q_{c^{(c)}} = -2/3$ and $Q_S = -1/3$ for this leptoquark.

We note that our expression for $F=-2$ leptoquark agrees with Ref. [9], but we have a different expression for $F=0$ leptoquark. Ref. [9] does not distinguish between these two types of leptoquarks.

Next, we use our expressions to fit to Δa_μ. The range of Δa_μ at 95% C.L. ($\pm 1.96\sigma$) is

$$10.3 \times 10^{-10} < \Delta a_\mu < 74.9 \times 10^{-10} \ . \tag{12}$$

A rough estimate for the allowed range of $M_{\rm LQ}$ can be obtained by realizing the dominant term in Eq. (9). In Eq. (9), the term with $\mathcal{R}e(\lambda_L \lambda_R^*)$ dominates over the term with $(|\lambda_L|^2 + |\lambda_R|^2)$, because of the enhancement factor of m_c/m_μ. This is valid as long as $\lambda_L \approx \lambda_R$. Also, the function $F_6(x) \to (-3 - 2\ln x)$ and $F_3(x) \to 1$ when $x \to 0$. Therefore,

$$\Delta a_\mu(\mathcal{S}_{1/2}) \simeq \frac{-1}{8\pi^2} \frac{m_c m_\mu}{M^2_{\mathcal{S}_{1/2}}} \mathcal{R}e(\lambda_L \lambda_R^*) \, (26) \ , \tag{13}$$

where the numerical factor of 26 is estimated by varying $M_{\mathcal{S}_{1/2}}$ between $0.5 - 1.5$ TeV. With the 95% C.L. bound on Δa_μ we obtain

$$2.6 \ \text{TeV} < \frac{M_{\mathcal{S}_{1/2}}}{\sqrt{-\mathcal{R}e(\lambda_L \lambda_R^*)}} < 7.2 \ \text{TeV} \ . \tag{14}$$

Similarly, for the $F = -2$ leptoquark $\mathcal{S}_0$ we obtain

$$2.5 \ \text{TeV} < \frac{M_{\mathcal{S}_0}}{\sqrt{-\mathcal{R}e(g_L^* g_R)}} < 6.7 \ \text{TeV} \ . \tag{15}$$

If $\lambda_L = -\lambda_R = e$ and $g_L = -g_R = e$, where $e = \sqrt{4\pi\alpha_{\rm em}}$,

$$0.8 \ \text{TeV} < M_{\mathcal{S}_{1/2}} < 2.2 \ \text{TeV} \qquad \text{and} \qquad 0.7 \ \text{TeV} < M_{\mathcal{S}_0} < 2.0 \ \text{TeV} \ . \tag{16}$$

We show in Fig. 1 the contributions to Δa_μ from the $F = 0$ and $F = -2$ leptoquarks $\mathcal{S}_{1/2}$ and $\mathcal{S}_0$ respectively, using the exact expression of Eq. (9). We have used $\lambda_L(g_L) = -\lambda_R(g_R) = e$. The shaded region is the 95% C.L. range allowed as in Eq. (12). One can see from the graph that the bounds on $M_{\mathcal{S}_{1/2}}$ and $M_{\mathcal{S}_0}$ are very close to the estimate in Eq. (16).

What about the other leptoquarks that have only the left- or right-handed coupling? We can use Eq. (9) with only λ_L or λ_R, then Δa_μ is given by

$$\Delta a_\mu = -\frac{N_c}{16\pi^2} \frac{m_\mu^2}{M^2_{\rm LQ}} |\lambda_L|^2 (Q_c F_5(x) - Q_S F_2(x)) \ . \tag{17}$$

The factor in the parenthesis is only a fraction of unity. Thus, this Δa_μ is suppressed by about 10^{-3} relative to the contributions from $\mathcal{S}_{1/2}$ or $\mathcal{S}_0$. Hence, the mass limits are weakened by a factor of $\sqrt{10^{-3}} \approx 0.03$, which means the leptoquarks are to be lighter than 100 GeV in order to explain the $a_\mu^{\rm exp}$. It is obviously ruled out by the Tevatron direct search limit on the second-generation leptoquarks [1] (see below).

We note that these two leptoquarks also give rise to an electric dipole moment (EDM) of muon, provided that $\mathcal{I}m(\lambda_L \lambda_R^*)$ is nonzero. The contribution to EDM is given by

$$d_\mu = \frac{e N_c}{32\pi^2} \frac{m_c}{M^2_{\rm LQ}} \mathcal{I}m(\lambda_L \lambda_R^*)(Q_c F_6(x) - Q_S F_3(x)) \ , \tag{18}$$

where d_f is defined by $\mathcal{L} = (-i/2) d_f \bar{f} \sigma_{\mu\nu} \gamma_5 f F^{\mu\nu}$. Note that the same large numerical factor, scaling as $\ln(M^2_{\rm LQ}/m_c^2)$, is in the parenthesis.

We also note that the self-energy diagram of the muon with the leptoquark and charm quark inside the loop gives a radiative correction to the muon mass. We calculated this diagram and found that it has an UV divergent piece and a finite piece. While the divergent piece is absorbed into the renormalization constant, the finite piece is given by $\delta m_\mu \sim (N_c \lambda^2/16\pi^2) m_c \ln(M^2_{\rm LQ}/m_\mu^2)$. Numerically, δm_μ is less than the observed muon mass for $\lambda \simeq e$ and $M_{\rm LQ} \simeq 1-2$ TeV, such that δm_μ can be included into the definition of the pole mass without any fine tuning problem, which gives the observed muon mass.

Summarizing, only the leptoquarks $\mathcal{S}_{1/2}$ and $\mathcal{S}_0$ that couple to both left- and right-handed muon can explain the data on Δa_μ, while the other leptoquarks alone cannot explain the data. In fact, it is advantageous to have the

coexistence of other leptoquarks because they can satisfy constraints from other experiments and at the same time would not give any sizable contribution to a_μ.

The most obvious limits on leptoquarks are the direct search limits at the Tevatron $p\bar{p}$ collision and at the HERA $e^\pm p$ collision, based on two NLO calculations [14]. Both CDF and DØ searched for the first and second generation leptoquarks. Their limits are independent of the leptoquark couplings because the production is via the strong interaction. The lower limits on the first (LQ1) and second (LQ2) generation scalar leptoquarks are given by [1]

$$
\begin{aligned}
&M_{\mathrm{LQ1}} > 242 \text{ GeV} \ \text{ for } \beta = 1 \qquad \text{(CDF and DØ combined)} \ , \\
&M_{\mathrm{LQ2}} > 202 \ (160) \text{ GeV} \ \text{ for } \beta = 1(0.5) \qquad \text{(CDF)} \ , \\
&M_{\mathrm{LQ2}} > 200(180) \text{ GeV} \ \text{ for } \beta = 1(0.5) \qquad \text{(DØ)} \ ,
\end{aligned} \tag{19}
$$

where $\beta = B(\mathrm{LQ} \to \ell q)$. At HERA, the direct searches are limited to the first generation leptoquarks and depend on the leptoquark couplings. The best limits with $\lambda = e$ are [2]

$$M_{\mathrm{LQ1}} > 280 \text{ GeV} \qquad \text{(ZEUS)} \ , \tag{20}$$

$$M_{\mathrm{LQ1}} > 275 \text{ GeV} \qquad \text{(H1)} \ . \tag{21}$$

The leptoquark solutions in Eq. (16) are safe with these limits.

There are also other existing constraints. Especially, if the first-second-generation universality is assumed for the leptoquarks, very strong constraints come from low energy and high energy experiments [15,16]. Among the constraints the APV and the CC universality are the most relevant to leptoquarks.

First-second-generation universality

It is convenient to parameterize the effective interactions of leptoquarks in terms of contact parameters $\eta^{\ell q}_{\alpha\beta}$, where α and β denote the chirality of the lepton and the quark, respectively, when the mass of the leptoquarks are larger than the energy scale of the experiment. The contact parameters are defined by

$$\mathcal{L}_\Lambda = \sum_{\ell,q} \left\{ \eta^{\ell q}_{LL} \overline{\ell_L}\gamma_\mu \ell_L \overline{q_L}\gamma^\mu q_L + \eta^{\ell q}_{LR} \overline{\ell_L}\gamma_\mu \ell_L \overline{q_R}\gamma^\mu q_R + \eta^{\ell q}_{RL} \overline{\ell_R}\gamma_\mu \ell_R \overline{q_L}\gamma^\mu q_L + \eta^{\ell q}_{RR} \overline{\ell_R}\gamma_\mu \ell_R \overline{q_R}\gamma^\mu q_R \right\} \ . \tag{22}$$

The APV is measured in terms of weak charge Q_W. The updated data with an improved atomic calculation [17,18] is about 1.0σ larger than the SM prediction, namely, $\Delta Q_W \equiv Q_W(\mathrm{Cs}) - Q_W^{\mathrm{SM}}(\mathrm{Cs}) = 0.44 \pm 0.44$. The contribution to ΔQ_W from the contact parameters is given by [15,16]

$$\Delta Q_W = (-11.4 \text{ TeV}^2) \left[-\eta^{eu}_{LL} + \eta^{eu}_{RR} - \eta^{eu}_{LR} + \eta^{eu}_{RL} \right] + (-12.8 \text{ TeV}^2) \left[-\eta^{ed}_{LL} + \eta^{ed}_{RR} - \eta^{ed}_{LR} + \eta^{ed}_{RL} \right] \ . \tag{23}$$

Another important constraint is the CC universality. It is expressed as $\eta_{CC} = \eta^{ed}_{LL} - \eta^{eu}_{LL} = (0.051 \pm 0.037)\ \text{TeV}^{-2}$. These ΔQ_W and η_{CC} are the two most important constraints relevant to leptoquarks. With the first-second-generation universality $\eta^{eu}_{\alpha\beta} = \eta^{\mu c}_{\alpha\beta}$ and $\eta^{ed}_{\alpha\beta} = \eta^{\mu s}_{\alpha\beta}$. We are going to analyze the leptoquark solutions that we found above with respect to these two constraints. Other high energy experiments such as HERA deep-inelastic scattering, Drelly-Yan production, and LEPII hadronic cross sections also constrained leptoquarks, but are relatively easy to satisfy with TeV mass leptoquarks [15].

For the $F = 0$ leptoquark $\mathcal{S}_{1/2}$ with the interaction given in Eq. (8), the contributions to η are

$$\eta^{\mu c}_{LR} = -\frac{|\lambda_L|^2}{2M^2_{\mathcal{S}_{1/2}}} \ , \qquad \eta^{\mu c}_{RL} = -\frac{|\lambda_R|^2}{2M^2_{\mathcal{S}_{1/2}}} \ , \tag{24}$$

which are equal to $-(0.01 - 0.07)\ \text{TeV}^{-2}$ for $\lambda_L = -\lambda_R = e$ and the mass range in Eq. (16). Similarly for the $F = -2$ leptoquark $\mathcal{S}_0$ with the interaction given in Eq. (10), the contributions to η are

$$\eta^{\mu c}_{LL} = \frac{|g_L|^2}{2M^2_{\mathcal{S}_0}} \ , \qquad \eta^{\mu c}_{RR} = \frac{|g_R|^2}{2M^2_{\mathcal{S}_0}} \ , \tag{25}$$

which are equal to $0.01 - 0.08\ \text{TeV}^{-2}$ for $g_L = -g_R = e$ and the mass range in Eq. (16).

Both of these leptoquarks do not contribute to ΔQ_W as the contributions get canceled. While $\mathcal{S}_{1/2}$ does not contribute to η_{CC}, $\mathcal{S}_0$ contributes to η_{CC} but in the opposite direction. The lower mass range of $\mathcal{S}_0$ is then ruled out by the η_{CC} constraint.

As mentioned above, coexistence of other leptoquarks could satisfy the constraints on ΔQ_W and η_{CC}. The ΔQ_W constraint can be satisfied by the coexistence of either ${\mathcal{S}^R_{1/2}}^{(-2/3)}$ with interactions $-\lambda_R\, \overline{e_R}\, d_L\, {\mathcal{S}^R_{1/2}}^{(-2/3)} + h.c.$, or $\vec{\mathcal{S}}_1^L$ with interactions $-g_{3L}(\overline{u_L^{(c)}} e_L\, \mathcal{S}_1^{L(1/3)} + \sqrt{2}\, \overline{d_L^{(c)}} e_L\, \mathcal{S}_1^{L(4/3)}) + h.c.$ [15]. The mass required to fit to ΔQ_W is $M_{\mathcal{S}^R_{1/2}} = 1.2$ TeV or $M_{\vec{\mathcal{S}}_1^L} = 2.0$ TeV with electromagnetic coupling strength. For such heavy leptoquarks with only a left-handed or right-handed coupling, their contributions to Δa_μ are certainly negligible. At the same time $\vec{\mathcal{S}}_1^L$ contributes to η_{CC} in the right direction, while ${\mathcal{S}^R_{1/2}}^{(-2/3)}$ does not.

Summarizing, we can have the following three viable combinations of leptoquarks.

1. ${\mathcal{S}_{1/2}}^{(-5/3)}$ and $\vec{\mathcal{S}}_1^L$. The former explains Δa_μ and the latter satisfies ΔQ_W and in the right direction as η_{CC}. This is the best scenario.

2. ${\mathcal{S}_{1/2}}^{(-5/3)}$ and ${\mathcal{S}^R_{1/2}}^{(-2/3)}$. The former explains Δa_μ and the latter satisfies ΔQ_W. They both have no effect on η_{CC}, but it is fine.

3. $\mathcal{S}_0$ and $\vec{\mathcal{S}}_1^L$. The former explains Δa_μ but violates η_{CC}. The latter can help pulling the leptoquark solution within a reasonable deviation in η_{CC} and still partially explaining ΔQ_W.

No first-second-generation universality

In this case, virtually no constraints exist on the second generation leptoquarks. The constraint of $D_s^+ \to \mu^+ \nu$ mentioned in Ref. [9] only applies to a very low leptoquark mass, which has already been ruled out by direct search [1]. There was a low-energy muon deep-inelastic scattering experiment on carbon [19]. An analysis [20] showed that this μC experiment results in a constraint

$$2\Delta C_{3u} - \Delta C_{3d} = -1.505 \pm 4.92 \tag{26}$$
$$2\Delta C_{2u} - \Delta C_{2d} = 1.74 \pm 6.31 \tag{27}$$

where $\Delta C_{2q} = (\eta_{LL}^{\ell q} - \eta_{LR}^{\ell q} + \eta_{RL}^{\ell q} - \eta_{RR}^{\ell q})/(2\sqrt{2} G_F)$ and $\Delta C_{3q} = (-\eta_{LL}^{\ell q} + \eta_{LR}^{\ell q} + \eta_{RL}^{\ell q} - \eta_{RR}^{\ell q})/(2\sqrt{2} G_F)$. The leptoquark solutions of $\mathcal{S}_{1/2}$ and $\mathcal{S}_0$ give $\Delta C_{2q} = 0$ and $\Delta C_{3q} \sim -10^{-3}$. Therefore, the constraint from the μC scattering is too weak to affect the leptoquark solutions.

We conclude that the 2.6σ deviation in the recent a_μ measurement places useful constraints on leptoquark models. To account for the a_μ data the leptoquark must have both the left- and right-handed couplings to the muon. Assuming that the couplings have electromagnetic strength, the mass is restricted to be about 0.7 TeV $< M_{\rm LQ} <$ 2.2 TeV. If no first-second-generation universality is assumed, this mass range is well above the direct search limit at the Tevatron. On the hand, if the first-second-generation universality is assumed, constraints also come from other low energy and high energy experiments, among which the atomic-parity violation and charged-current universality are the most important. We have shown that coexistence with other leptoquarks can satisfy these additional constraints and at the same time do not affect the a_μ. Leptoquarks in such a mass range should be produced at the LHC via the strong interaction.

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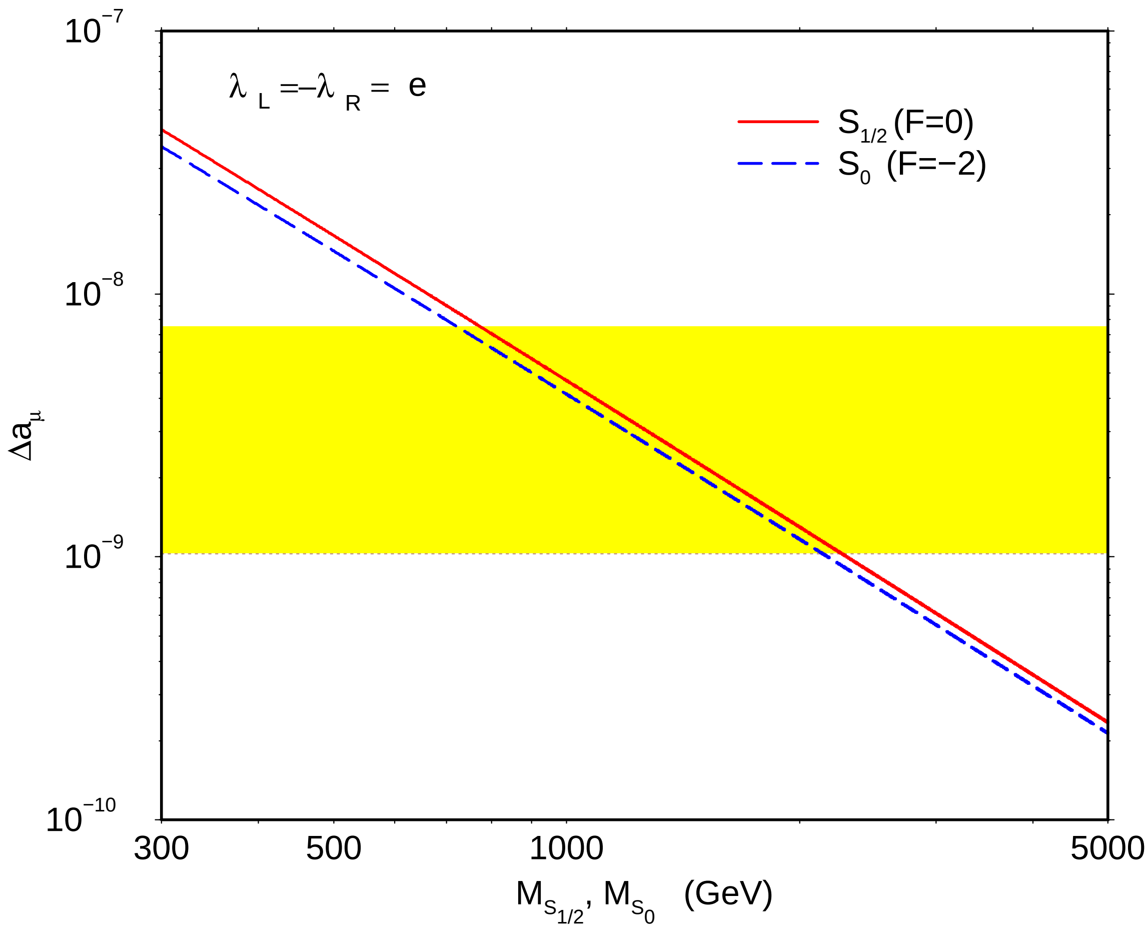

FIG. 1. Contributions to Δa_μ from the $F = 0$ leptoquark $\mathcal{S}_{1/2}$ and the $F = -2$ leptoquark $\mathcal{S}_0$. The shaded region is the 95% C.L. range of Δa_μ given in Eq. (12).